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Permeability of Cement Mortars

Civil Engineering

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PERMEABILITY OF CEMENT MORTARS

BY

HARRY SAVIDGE

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

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COLLEGE OF ENGINEERING

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This is to certify the following thesis prepared under the immediate direction of Mr. L. G. Parker, Instructor in Civil Engineering, by

HARRY SAVIDGE

entitled PERMEABILITY OF CEMENT MORTARS

is accepted by me as fulfilling this part of the requirements for the Degree of Bachelor of Science in Civil Engineering.

Ira O. Baker

Head of Department of Civil Engineering.

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Permeability of Cement Mortars

1 Introduction

2 Compiled Data

3 Analysis of Materials

(a) cement { 1 fineness
2 tensile tests

(b) Sand { 1 sieve analysis
2 voids

4 Description of Apparatus

(a) discs
(b) tee
(c) molds

5 Discussion of Results

6 Conclusions

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PERMEABILITY OF CEMENT MORTARS

INTRODUCTION

The displeasing effect due to water-seepage or percolation thru concrete is a live topic for discussion among practicing engineers, and unless there is obtained a successful method of preventing such percolation in places where an architectural effect is essential, concrete must recede from its present position and yield to natural building materials. Much study has been put upon impervious concrete by the

ablest engineers of our country, especially by those who are interested in the construction of dams, reservoirs, and tunnels.

The permeability of a material is that property which permits a liquid to pass thru when subjected to pressure, and should not be confused with porosity which is the power of a material to absorb a liquid and retain it in its interstices.

The writer made several laboratory tests on the permeability of cement mortars to determine the quantity of water passing thru blocks of mortar of various composition submitted to water pressure; also to determine whether or not variations in the proportions of both the sand and the water to the cement would effect the permeability of the mixture. In no case was a water-proofing material used.

Before planning his experiments the author examined all the literature on this subject which he could find, but unfortunately the literature is very meager. The author presents herewith a summary of all the available articles.

The subject of permeability of cement mortars will be presented here in the following order:- (1) discussion of compiled data, (2) analysis of the materials, (3) description of the author's apparatus, (4) discussion of the results, and (5) conclusions.

I COMPILED DATA

The data compiled here were compiled from the following sources:- (a) "Permeability of Cement Mortars" translated by Mr. L. M. Haupt; (b) "Experimental Researches upon Hydraulic Mortars" by M. Paul Alexandre; (c) "Permeability of Concrete under High Water-pressure" by messrs. J. B. McIntyre and A. L. True; (d) "Cement and Concrete" by Sabin; and (e) "Impervious Concrete" discussion before Am. Soc. of C.E. The most extensive quotation is from the discussion of "Impervious Concrete" before the American Society of Civil Engineers, led by Mr. R. W. Lesley

(a) Haupt's article

The earliest reference found on the subject of permeability of cement mortars is

a translation of French tests by L. M. Haupt, found in Journal of the Franklin Institute, Vol. 127, published in 1889.

Preliminary tests were made with apparatus shown in Fig. 1. This apparatus consisted simply of a tube one meter long held by wax to the concrete block, A, which was being tested.

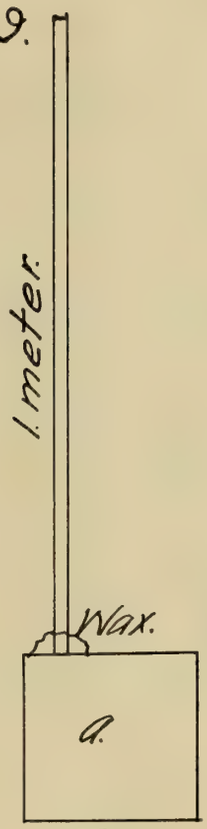
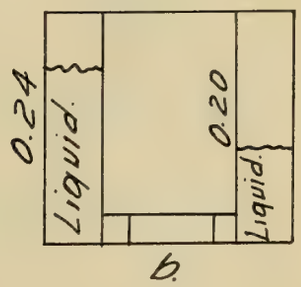


Fig. 1.



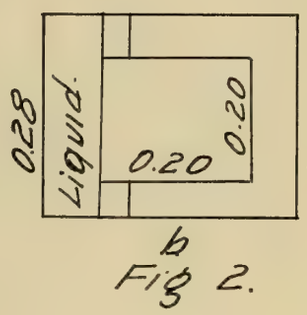


Fig 2.

The apparatus shown in Fig. 2 was finally adopted for making the tests. It consisted of an earthen vessel in which were molded the concrete blocks, on one face of which water pressure could be applied.

A six per cent solution of sulphate of magnesia was applied to a face of one of the blocks with a pressure of 10 centimeters head.

The solution which filtered thru was withdrawn periodically. After being under pressure about 16 days, an expansion in the blocks was noticeable. After 20 days the expansion of the blocks burst the earthen vessels in which they were placed. In several series of tests the experimenters first submitted the block to filtration with clean water, then with water containing 6 per cent of sulphate of magnesia, followed by water containing 30 per cent of the same salt.

The conclusions derived from the above tests were:- (1) That filtration with pure water had removed a certain proportion of the lime existing in the mortar and coming from the cements; (2) that under the action of water charged with sulphate of magnesia, part of the lime contained in the mortar disappeared, whilst the proportion of magnesium and

sulphuric acid is found to increase."

b. Alexandre's Experiments.

An extract from "Experimental Researches upon Hydraulic Mortars" by M. Paul Alexandre, in the Engg News, Vol. 25, page 40, shows: "Other things being equal the permeability of mortars is increased as the proportion of cement decreases; it increases with the coarseness of the sand used; mortars made with a mixture of sand of various sizes are relatively more porous and non-permeable.

"The permeability of mortars submitted to the continuous filtration of soft water or of sea water diminished rapidly with the time. At the end of some months, all the mortars (except those of a feeble dosing of cement) became impermeable under a head of 16 inches of water; the mass of mortar being 1 1/8 inches thick. Mortars mixed dry are more permeable than those mixed wet, or of a 'normal'

consistency, but at the end of some months these too became impermeable."

c. Experiments of Mc. Intyre and True.

The following is the manner of testing concrete and the conclusions drawn by J.B. Mc. Intyre and A.L. True in their thesis work on "Permeability of Concrete under High Water Pressure", at the Thayer School of Engineering- see Eng. News, Vol. 47, page 517.

Cylindrical specimens (see Fig. 3) were made in pairs of two kinds of cement, 9 inches high and 10 inches in diameter; and had an 8 inch length of $\frac{3}{4}$-inch pipe inserted to a depth of 4 inches in the top, thus leaving at least 5 inches of concrete in every direction to be penetrated by the water. Around the bottom of the pipe, a check-nut was placed, and this was surrounded by a little neat cement to prevent the water from forcing its way to the top along

the pipe. The preceding is a description obtained in the Eng. News; but the writer wishes to call attention to the fact that there is not 5 inches to be penetrated by the concrete as is stated.

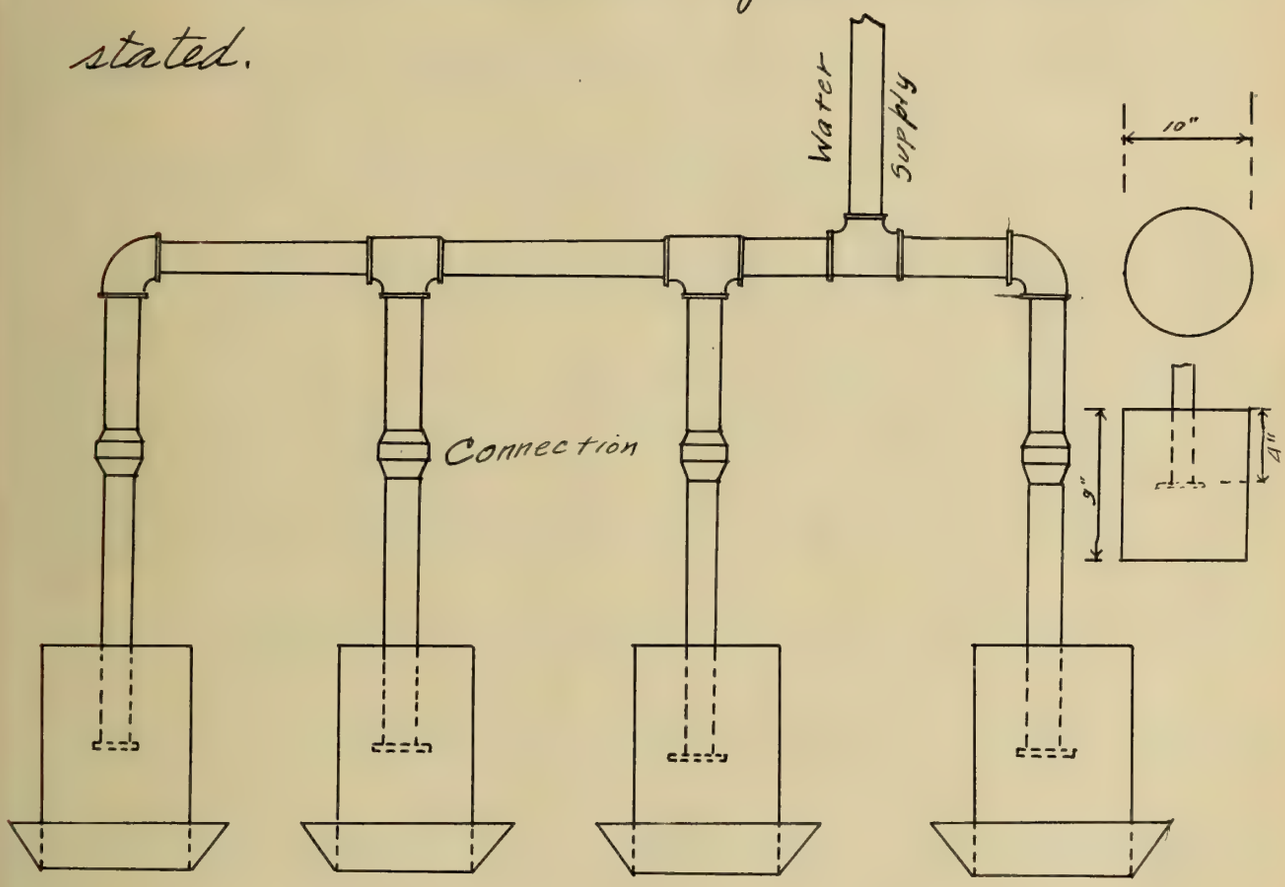


Fig. 3

The concrete was placed in galvanized iron molds in layers of about 3 inches, and solidly rammed with a wooden rammer. When a depth of 5 inches was reached the

iron pipe was put in place, the pat of neat cement rammed around it, and the mold filled to the top.

The experimenters concluded that: "all the specimens composed of 1:1 mortar, 30, 35, 40, and 45 per cent of the whole mass were impermeable. Some of the specimens composed of 1:2 mortar, 40 to 45 per cent were also impermeable, as well as the mixtures 1:2:4 and 1:2½:4. All others leaked at the high pressures. The pressures used thruout the test were 20, 40, and 80 lbs. per square inch. The specimens which showed no leak in 2 hours were left under pressure 24 hours, and at the end of that time no leak appeared in any case."

d. Sabin's Results.

Statements concerning the importance of good mortar may be found in

"Cement and Concrete" (Page 342) by Sabin. The following are a few facts dealing with the permeability of mortars: "The life of the structure being dependent upon the mortar it is essential that the mortar be not carried away by water. In the case of concrete the permeability diminishes as the per cent of mortar increases, at least to the point where the latter is in excess of the voids in the stone. Mortars made with fine sand are much less permeable than those of ordinary consistency; and in the case of concrete it would probably be found that a deficiency of water would result in a much more permeable mass than the use of what might be considered an excess. While it is necessary to have fine particles of sand present, another requisite is the fine grinding of the cement used."

e. Discussion before the American Society of Civil Engineers

In the last few years the securing of impervious concrete has been such a live topic that the American Society of Civil Engineers called for a discussion of the subject "Impervious Concrete" — see the transaction Vol. 51, page 114 et seq.

The discussion on impervious concrete was led by Mr. R. W. Lesley who quotes M. R. Feret, a French engineer, chief of the Boulogne Laboratory as an authority on the subject, whose conclusions in regard to porosity and permeability were:

"Porosity of cement mortars varies very greatly, diminishing as the proportion of cement increases; and is much greater when the sand is finer.

"'The permeability of mortars diminishes

as the proportion of cement is increased; but, reversing the conditions applying to porosity, permeability increases according to the size of the sand grains. Mortars made with sand composed of different sized particles which themselves have little porosity has also very slight permeability.

"Permeability is quite a different subject from porosity, and the effect of the passage of water may be said to free small particles of the lime or cement and bring them to the surface, where they produce efflorescence or fine stalactites, according to the freshness of the mortar. When water is forced thru a mass of mortar, stone-work or concrete, or is allowed to go thru freely, the fact that large amounts do go thru at once does not indicate any lack of value in the mortar, since the first hour may show a

considerable quantity of water passing thru. The water carries lime particles which close the pores, and as the process is kept up, each hour shows a diminished volume of percolation."'

Mr. Iesley concludes from M. Feret's experiments that at the end of a week's test practically no water percolated thru the test piece. He concludes also that: "This was due to the fact that the pores were obstructed by the carbonates of lime which result from the attack of the cement by the water carrying lime passing thru it, and its subsequent exposure to the atmostphere.

"As a general rule it is observed that this lessening of the permeability of the mortar is just as much more rapid as the filtration thru the mass is abundant. In reference to this it would appear that where, after

a long drying, mortar is subjected to water and there is a great quantity pouring thru immediately, this is the best indication that the mortar ultimately will be absolutely impermeable to water".

2 ANALYSIS OF MATERIALS

A study of the permeability of mortar reveals many things that tend to influence the passage of water thru the material, and for this reason anything which can possibly produce variations in the results should be noted. The character of the materials doubtless has much to do with the results obtained, therefore mechanical tests have been made of the cement and the sand.

Cement

Chicago U. S. Portland Cement, which is being used at the present time for concrete tests by the Engineering Experiment Station was used in these experiments.

Sieve analyses of the cement and tensile tests of the mortars were made and the results are shown in Table I, page 17.

Sieve Analyses. — The sieve analyses were made to find the percentages of cement passing thru the following standard sieves: Nos. 74, 100, and 200. The results given in Table I are the averages for eight tests for fineness.

TABLE. I.
SIEVE ANALYSIS.
Average of Eight Tests.

Sieve No.	Per Cent Passing Thru.
74.	96.3.
100.	91.2.
200.	69.7.

Tensile Tests. — The tensile strength of the mortars used in making the test blocks was determined. These mortars were mixed in the following proportions:- neat, 1:1, 1:2, and 1:3

with varying percentages of water. The briquettes used in these tests were all thumb-rammed; the upper surface having a trowelled finish; and were tested at the ages of 7 and 28 days. The average strength of the briquettes is shown in Table II, page 10 The tests show that all of the briquettes made with the smaller per cents of water were the stronger except those made of neat cement tested at the age of 28 days.

TABLE II.

STRENGTH OF BRIQUETTES.

No of Briquettes.	Proportion of Mortar.	Per Cent Water.	Strength lbs per sq in.	
			7 day.	28 days.
6.	Neat.	25.	635.	812
6.	Neat.	22½.	671.	805.
6.	1:1	14.	555.	676.
6.	1:1	15.	500.	586.
6.	1:2	12½.	338.	508.
5.	1:2	13.	308.	385.
5.	1:3	11½.	260.	365.
6.	1:3	12½.	191.	292.

Sand

The sand was good silica building sand such as was used by the Engineering Experiment Station in its last series of reinforced concrete tests. The sand was analized to determine the variation of sizes of the grains, the amount of clay present, and the percentage of voids.

Sieve Analysis.- In order to determine the variation in the sizes of the grains 2000 grams of sand were carefully weighed and thoroughly washed. The sand was then dried for 24 hours and again weighed. This loss in weight between the original mass of sand and the washed sand represents the quantity of clay present. The washed sand was passed thru sieves having holes of the following diameters: $\frac{1}{8}$", $\frac{1}{16}$", $\frac{1}{32}$", and a standard 100 mesh siene. The results

of the test are shown in Table III.

TABLE III.

SIEVE ANALYSIS OF THE SAND.

Sieve	Retained on Sieve.	
	Grams.	Per Cent.
$\frac{1}{8}$"	4.	0.2
$\frac{1}{8}$" - $\frac{1}{16}$"	104.	5.2
$\frac{1}{16}$" - $\frac{1}{32}$"	630	31.5
$\frac{1}{32}$" - 100	1188.	59.4
Thru 100.	39.	1.95
Clay.	35.	1.75
Total.	2000.	100.00

Determination of Voids. — In order to obtain the amounts of voids in the sand the following method was employed: Into a half-gallon fruit jar filled about one-third full of water, a small scoopful of sand was poured slowly. The contents were gently shaken until the air-bubbles around the sides of the jar disappeared. The process was repeated by the addition of more sand and water until

the jar was entirely filled. At frequent intervals a small wire was inserted in order to churn the sand thus making sure that all interstices were filled and that the sand did not separate into strata of the sizes. The surface of the water was kept always above the sand to prevent the admission of air into the mass of sand and water. Air bubbles in the sand or the stratification of the sand cause a greater percentage of voids. In determining the percentage of voids it was necessary to find the amount of water which the jar full of sand would receive, the ratio of the latter to the former being the proportion of voids.

The result obtained was as follows:

Weight of water required to fill the jar = 1421.4 grams.
Weight of water required to fill the voids = 567.1 "

$$\text{Per cent of voids} = \frac{100 \times 567.1}{1421.4} = 40.8$$

3 DESCRIPTION OF APPARATUS

In making experiments on the permeability of mortars, the writer considered it necessary to have test pieces of such shape that the water would pass thru a uniform cross-section, thus requiring the use of slabs having parallel faces. The most convenient form of apparatus at hand for holding such test pieces was found to be a 6"×6"×4" cast-iron water-tee. The test pieces were discs molded to fit the 6 inch bells. A vertical section of the water chamber and the disc in place is shown in Plate I, at the end of this volume.

Discs.- The test pieces or discs were made of mortar in the following proportions: neat, 1:1, 1:2, and 1:3. The neat cement was mixed with water in the proportions of 18, 20, 22½, 23, 24, and 25

per cents; the 1:1 with 14, 14½, and 15½ per cents; the 1:2 with 12½ and 13 per cents; and the 1:3 mixture with 11½ and 12½ per cents of water.

Molds.– The first discs were made in a wooden mold which formed cylindrical test pieces 7½ inches in diameter and 2 inches thick. These discs were afterwards ground on an emery wheel to give them the shape and size of the discs which were made later. These later discs were made in a mold which formed them into frustrum of cones having the larger diameter 7½ inches and the smaller diameter 6¾ inches, the thickness remaining 2 inches. The surface of the disc having the larger diameter was trowelled, and is called the finish face. All markings were made on the smaller or unfinished faces of the discs. Both molds and several of the discs are shown in Plate II.

The method of placing the discs in the bell of a tee was as follows: The interior shoulder of the bell was given a coating of neat cement containing 20 per cent of water. A similar treatment was given to the slanting surface of the discs which were afterwards placed with the finished face against the interior shoulder of the bell. Many methods were tried to secure a water-tight seal between the slanting surface of the disc and the tee, but the only successful one consisted in working dry cement into jute fibers and then calking the jute around the disc. Since it was desired to have the water pass thru the same area on the outer face as it did at the inner, the discs were covered with neat mortar to a thickness of $\frac{1}{2}$ inch, except for a circular space at the center having a diameter of 6 inches.

The discs put in the tee at the same time were of the same proportion and the same age, and contained the same percent of water.

Plate III shows the general arrangement of the apparatus. The water pressure was obtained from the city main, and the head varied from 92 to 110 feet, as read by the ordinary pressure gage.

Plate III also shows the scheme for collecting the water. The pans covering the ends of the tees were placed there to reduce the amount of evaporation and to collect the water passing thru the discs. Water collecting in the corners of the pans dropped from the pans into funnels leading to the covered jars. This manner of collecting water did not prevent evaporation entirely; but since this plan was used thruout, the errors that may have existed would effect all of the results alike

so will not be mentioned further.

The results obtained with the preceding apparatus are shown in Table IV.

TABLE IV.

PERCOLATION IN OUNCES PER SQUARE INCH FOR SUCCESSIVE DAYS.

Ref No.	No of the Disc.	Per Cent of Water.	Age in Wks	Days under Test. 1.	2.	3.	4.	5.	6.	7.	Remarks.
				NEAT MORTAR.							
1.		18 20, 22½	4 to 8.	No trace of percolation.							12 Discs were used in this test.
2.		23, 24, 25									
				PROPORTIONAL 1:1.							
3.	24, 34, 35.	15.	4.	Very little moisture around the edge.							
4.	11, 14, 16.	14.	4								
5.	27	15½	3.	1.22	1.12	0.94	0.89	0.82	0.78		Defective Packing.
6.	23	14½.	4.	0.23	0.20	0.14	0.10	0.80	0.7	.05	Entire Surface Damp
7.	15.	14.	7.	0.57	0.51	0.41	0.26	0.23	0.09	0.04	Defective.
8.	17.	14.	7.	0.61	0.51	0.48	0.31	0.29	0.21	0.10	Packing.
				PROPORTIONAL 1:2.							
9	18	12½	8	0.23	0.20	0.14	0.12	0.10	0.10		Percolation
10	19	12½	8	0.23	0.16	0.10	0.04	0.02	0.14		over
		Averages		0.23	0.18	0.12	0.08	0.06	0.12		the
11	36	13	4	0.41	0.38	0.31	0.25	0.20			entire
12	37	13	4	0.26	0.23	0.20	0.14	0.12			face.
1		Averages.		0.34	0.30	0.26	0.20	0.16			
				PROPORTIONAL 1:3.							
13	20	11½.	4.	0.63	0.39	0.33	0.30	0.16			
14	21	11½.	4.	0.70	0.55	0.51	0.41	0.31			Percolation
		Average.		0.66	0.47	0.42	0.36	0.24			over the
15	38	12½	10.	0.063	0.15	0.17	0.18	0.18	0.16		entire
16	39	12½	10.	0.06	0.04	0.06	0.08	0.10	0.07		face.
		Average.		0.06	0.09	0.11	0.13	0.14	0.11		

4 DISCUSSION OF THE RESULTS

Neat Mortar

The most noticeable features of Table IV are: There is no percolation thru neat cement mortar - see lines 1 and 2 of Table IV. Twelve discs were used in this test, and the water used in making the discs varied from 18 to 25 per cent. This experiment continued for 7 days. At no time did even dampness appear on the face of any disc. The conclusion then is that neat cement mortar if thoroughly mixed and reasonably well tamped there will be no appreciable percolation. This conclusion agrees with that uniformly found by other experimenters. However this conclusion is not especially valuable as a guide in making masonry structures impermeable, since it is im-

practicable to build actual engineering structures of neat cement mortar.

1:1 Mortar

Lines 3 and 4 of Table IV show that there is hardly any percolation thru a 1:1 mortar, since only a slight dampness appeared around the edge of the discs. Notice that according to these observations that there is no appreciable difference in the permeability of mortar mixed with 14 per cent of water and that containing 15 per cent. Notice that, in the experiments recorded in lines 5, 7, and 8, there was defective packing which permitted leakage past the edge of the discs; and therefore these experiments are worthless.

Notice that line 6 gives a considerable percolation over the entire surface of the disc. The writer is unable to explain the difference between line 6 and lines 3 and 4, however other

experimenters report a marked difference in permeability as frequently occurring without any known difference in the proportions of the mortars, in the amount of water used in mixing, or in the method of mixing or placing the mortar.

1:2 Mortar

Lines 9 and 10 give the percolation thru mortar 8 weeks old and lines 11 and 12 thru mortar 4 weeks old. The average percolation thru the discs 8 weeks old is only one-half to two-thirds as much as for the discs 4 weeks old.

1:3 Mortar

A more marked difference of percolation is noticeable in this mortar between the averages of the discs found in lines 13 and 14 and 15 and 16 than was found in the 1:2 mortar. The ages of the discs were 4 and 10 weeks respectively; this difference

ranges from one-tenth to one-half as much as those tested at the age of 4 weeks.

With this percolation, in the 1:2 and 1:3 mortars, over the entire surface of the disc there appeared minute white particles on the outer surface which gradually increased, stopping the flow of water. These white particles or efflorescence are shown in Plate IV.

5 CONCLUSIONS.

From the results of Table IV it is apparent that there was a gradual decrease in the amount of percolation with the time the disc was under the test, and also with the age of the disc. The author advances two reasons for the above variations; 1st, as the cement discs become older the union between the sand and cement becomes firmer, consequently this adhesive tendency decreases the amount of water percolating. This fact is brought out more clearly by an examination of briquettes; even the neat ones which have been kept in pans of running water and broken when a few days old, show considerable water thruout the mass; but an increase

of sand also increases the amount of water present in the briquettes. When briquettes of neat cement are broken and examined there appears at an early age a small whitish core of dry material in the center of the briquettes; if kept for a longer period it is found that the core has enlarged from the center and has come out to the surface. Close examination also shows that from the surface inward there is very little percolation of water whatever. However, increasing the amount of sand in the briquettes likewise delays the appearance of the core; 2nd, the decrease of percolation with the length of time that the discs were under water pressure may be accounted for by the deposition, upon the surface and in the interior of the discs, of mineral matters in solution, of which iron was

present in an extra ordinary amount.

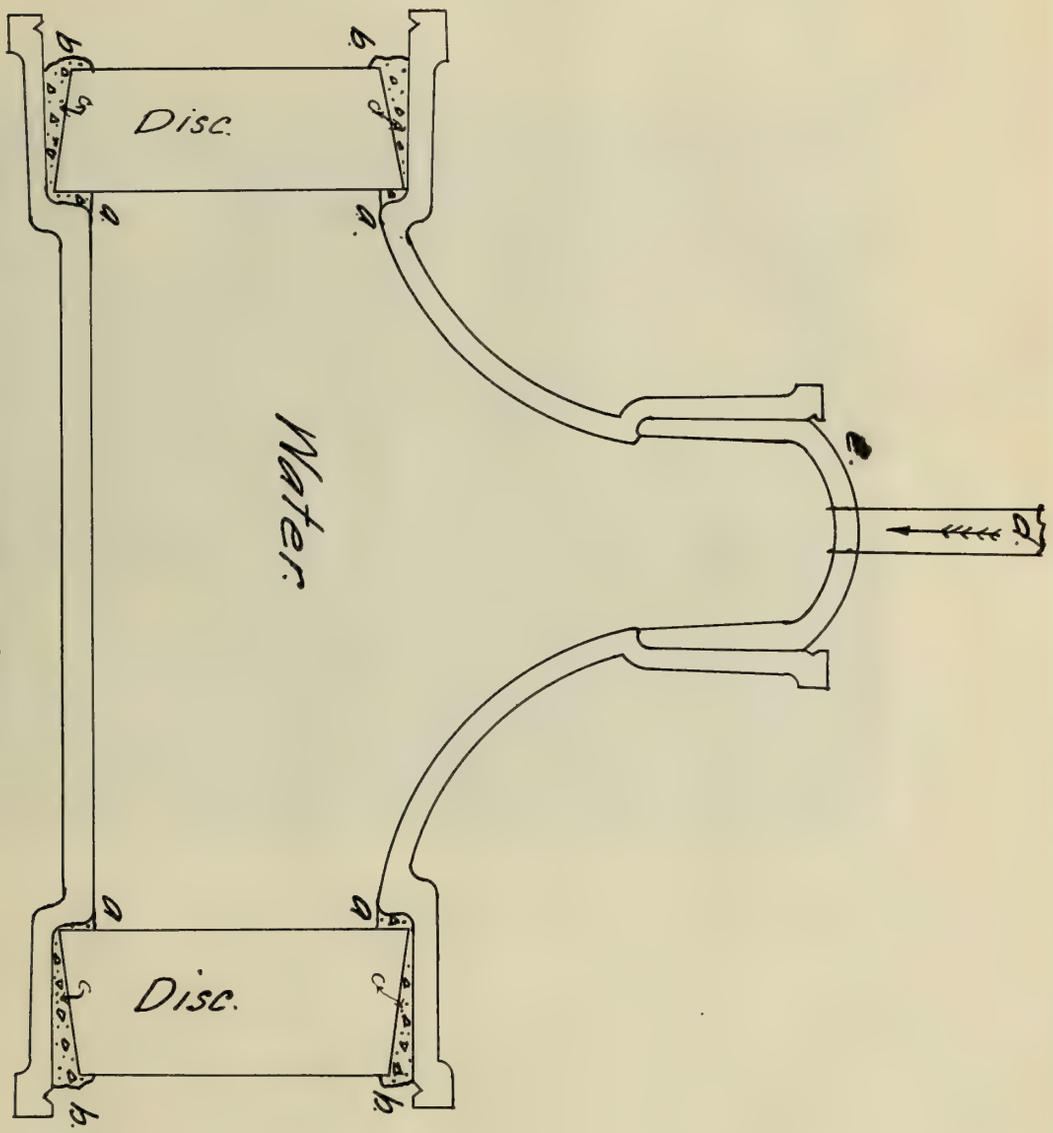
Again, if the proportions are considered, percolation varies directly with the ratio of sand to cement. With neat cement-pieces, no trace of percolation could be found; the amount of percolation became greater as the proportion of sand was increased.

Moreover, results seems to indicate that a minimum amount of percolation may be obtained from each class of mortar by using the correct proportion of water in the mixing. Furthermore an amount of water either more or less than this correct proportion will increase the permeability of the test piece. On first thought, it may seem strange that this double condition exists; when too much water is used small particles of the water remain free and affords an obstructed passage for any outside water;

on the other hand too little water will not bring about a perfect union between the cement and the sand.

Briefly stated, the undesireable effect in concrete structures caused by percolation of water may be eradicated and a waterproof surface be secured, by a correct proportioning (of the sand, cement, and water) used in the facing mortar of such structures.

PLATE, I.



a-a Finished Surface.
b Neat Mortar.
c Cuts.
d ¾" Pipe.
e ¾" Plug.
Scale 3"=1'

Plate II.

Plate III.

Plate IV.

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